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AN INVESTIGATION OF EARTHSHINE LIGHTING CONDITIONS FOR LUNAR-SURFACE OPERATIONS

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ABSTRACT

The results and conclusions derived from an evaluation of the lighting conditions produced by earthshine on the lunar surface are presented in this paper. The operations were conducted to determine the suitability of earthshine for lunar-nighttime operations, and although the results are subjective and limited in quantity, they indicate that earthshine is adequate for lunar-surface operations under the conditions which are specified and outlined in this study and evaluation.

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SUMMARY

Early Apollo missions are restricted by the necessity for good crew visibility during descent to landing sites near the sunrise terminator. For early Apollo missions, this site selection is also advantageous because it provides up to 14 days of sunlight conditions for lunar-surface operations. For post-Apollo missions, the restriction may not be necessary or optimum. Under this relaxed constraint, lunar-surface activities may extend into the lunar night when the surface is illuminated by earthshine. An evaluation of earthshine was conducted to determine its suitability for lunar-nighttime operations. Although the results obtained are subjective and limited in quantity, the results indicate that under certain conditions earthshine is adequate for lunar-surface operations.

INTRODUCTION

Present Apollo mission requirements stipulate that the lunar landing is to be made in sunlight within 7° to 20° of the sunrise terminator. The range of sun angles was chosen to afford high surface contrast for good crew visibility during the final approach and descent phases of the landing. The sunrise terminator was chosen because it placed the sun directly behind the spacecraft during the landing without requiring a dogleg maneuver to avoid visual impairment caused by glare. A landing near the sunrise terminator also assured sunlight during the lunar-surface operations. In addition, most of the descent from 80 nautical miles to 50 000 feet in altitude would also occur in sunlight, and, for short lunar-surface staytimes (such as 1-1/2 days), most of the ascent would occur over the unilluminated side of the moon. For early Apollo missions to near-equatorial lunar-landing sites, this choice of conditions is most advantageous.

For post-Apollo missions, this choice of conditions may not be necessary or optimum. Nonequatorial sites on the moon, highly inclined orbits, and dogleg maneuvers for landings may be operationally acceptable. Under one or more of these relaxed constraints, landings on the moon near the sunset terminator (in sunlight) may be equally as acceptable as landings near the sunrise terminator. Also, extended staytimes and the high-thermal loads associated with sun-illuminated operations may make operations in unilluminated areas necessary and desirable. Certain scientific experiments, such as those related to astronomy, may require operations in the absence of sunlight. For these reasons, it would appear to be desirable that the gathering of data be started immediately for the determination of the necessary conditions for acceptable lighting on the lunar surface which would be congenial for operations performed in areas not illuminated by the sun.

Another source of illumination on the moon is the earth. The face of the moon visible from earth may be wholly or partially illuminated either directly by the sun or indirectly by sunlight reflected by the earth. This latter condition, which is called earthshine, is analogous to moonlight on earth. Because of the higher albedo and the greater size of the earth, earthshine is more intense on the moon than moonlight is on the earth. Because of this fact, earthshine may produce sufficient light for lunar operations in areas not illuminated by the sun.

This paper is a report on a preliminary investigation to determine if earthshine would provide adequate lighting for lunar-surface operations and to determine the conditions in which adequate lighting would exist. The first portion of the investigation involves a limited subjective evaluation to determine the acceptability of simulated earthshine lighting for lunar operations. The last portion of the investigation is concerned with the application of the evaluation results to the problem of assessing the suitability of earthshine for lunar-surface operations and with the definition of the period during the so-called lunar night when suitable lighting would exist at a given landing site.

EARTHSHINE INTENSITY AND ITS PHYSICAL PROPERTIES

The intensity of earthshine at 0° phase angle is almost two orders of magnitude greater than moonlight on earth. The large difference is caused by the greater size and higher albedo of the earth. The projected area of the earth is about 16 times that of the moon, while its albedo, which is determined largely by the meteorological conditions of the earth, is about four times that of the moon. The albedo values of the earth vary from a minimum of 32 percent during the period from July to September to a maximum of 52 percent during the periods from March to June and from October to November, with the average albedo being 40 percent (ref. 1).

The earth, as seen from the moon, undergoes phase variations similar to those of the moon, but in an opposite manner. For example, when the moon is one-fourth full, the earth, as seen from the moon, will appear to be three-fourths full. The variation of earthshine intensity with phase, as reported in reference 1, is shown in figure 1. To give a visual conception of the maximum intensity of earthshine upon the moon, one may compare it to the intensity of moonlight on earth. When the moon is full and at the zenith, its intensity at the surface of the earth is 0.023×10^{-3} lm/cm^2 (ref. 2); when the earth is full in the lunar sky, the intensity of its illumination on the lunar surface, as given in reference 1, is 1.34×10^{-3} lm/cm^2 or 58 times greater than full moonlight on the earth.

Unlike the moon, the albedo of which is nearly independent of wavelength, the earth albedo decreases with increasing wavelength giving earthshine a bluish color.

Measurements of the color index of the earth have shown that earthshine reaches its maximum color shift when its intensity is maximum. The effect of earthshine color upon astronaut visibility was not considered in this study.

EVALUATION OF EARTHSHINE FOR LUNAR-SURFACE OPERATION

A limited subjective investigation of the acceptability of only earthshine for lunar operations was carried out in daylight utilizing neutral-density filters to simulate earthshine conditions. The solar-intensity values used for determining the simulated earthshine intensities are given in figure 2, and the filter-density values used are as follows.

Filter number	Percent of transmission
1	0.002
2	.004
3	.008
4	.023
5	.036

The lunar-surface simulation located at MSC was used as a test-bed. Although the surface, in appearance and light-scattering characteristics, did not closely match that which was photographed by the Surveyors, the surface was sufficiently rough (fig. 3) to provide conservative evaluation results. The albedo of the simulation varied from 5 percent in the dark regions to 25 percent in the lighter areas, closely matching albedo values which would be found on the moon.

In evaluating the acceptability of earthshine for lunar operations, two test subjects, dressed in street clothes, were employed. Each subject was provided with goggles and a set of neutral-density filters simulating a range of earth-phase intensities. After 5 minutes of adaptation time to a simulated earthshine condition, the test subjects were instructed to walk around on the test-bed and to make comments on the adequacy of the earthshine intensity simulated. The adequacy of the simulated earthshine conditions was based on two criteria evaluated subjectively by each test subject: (1) the ability to traverse the most difficult of the terrains with a sense of confidence, and (2) the capability of distinguishing the relief of distant features such as craters. After each filter test, each test subject indicated whether the earthshine simulated was good, marginal, or bad. It was assumed that an auxiliary light would be used to illuminate shadowed areas.

Because of time and weather limitations, only two earthshine-evaluation tests were conducted. At the time of the first evaluation, the solar elevation was 70°. When lunar librations are neglected, the elevation angle of the earth in the lunar sky is equal to the arc distance γ from the lunar mean libration point, where γ, in terms of lunar longitude λ and latitude β, is given by $\gamma = \cos^{-1}(\cos \lambda \cos \beta)$. Therefore, the results of this test corresponded to the lighting conditions existing at a landing site on the moon located 20° arc distance from the mean libration point on the moon. The results indicate that, for a landing site located at this position, the lighting conditions are good when the illumination level is 0.91×10^{-3} lm/cm^2 but are marginal when the illumination level is 0.44×10^{-3} lm/cm^2. At the marginal illumination level, the test subjects were just able to distinguish the size and relative position of surface relief such as rocks near their feet. The relief of distant features, such as craters, was distinguishable. At a simulated earthshine illumination level of 0.22×10^{-3} lm/cm^2, the test subjects indicated that the lighting was bad. Also, under this lighting condition, they were unsure of their ability to traverse the more difficult portions of the simulation without stumbling, and the relief of distant features could not be clearly distinguished.

At the time of the second evaluation, the solar elevation angle was 28° corresponding to a landing site on the moon with an arc distance of 52°, again disregarding lunar librations. Under these conditions, it was found that the illumination level required for good visibility depended on the direction that the test subject looked relative to the sun. When looking directly away from the sun, the level of illumination required for good visibility was nearly the same as that found in the first test. However, when the test subject walked in the direction of the sun, the required illumination level increased considerably. It was found that an illumination level of 2.26×10^{-3} lm/cm^2 is good for all directions observed, but the visibility conditions are marginal when the illumination level is 1.50×10^{-3} lm/cm^2. At 0.47×10^{-3} lm/cm^2, the test subjects were unable to evaluate the degree of roughness; and, as a result, they indicated a feeling of insecurity when walking around on the rougher portions of the lunar-surface simulation. The results of each earthshine evaluation test are shown in table I.

The earthshine evaluation results are plotted and extrapolated in figure 4 as lines of equal acceptability as a function of arc distance from the mean lunar libration point. The upward turn of the extrapolated lines arises from the large light intensity that would be required near the lunar limb regions to produce ample background brightness for acceptable visibility conditions. The lines have been given the subjective values of good, marginal, and bad. It should be noted that the wide difference between the good and bad lighting intensities was caused by the relatively large difference in the transmissions between the individual neutral-density filters used in the investigation. It is believed that if more filters had been employed, the wide range between good and bad earthshine conditions would be much smaller and would have converged on the values found to be marginal. In future investigations of this type, a greater number of filters should be used with smaller incremental differences in transmission. From such an investigation, precise boundaries between good and bad earthshine intensity values could be defined.

APPLICATION OF EARTHSHINE-EVALUATION RESULTS TO APOLLO MISSION PLANNING

The variation in earthshine with landing-site longitude has been plotted in figure 5 for each 24-hour increment after sunset. By superimposing the subjective acceptability data of figure 4 on the actual lighting data of figure 5, the periods of good, marginal, and bad lighting may be determined for any given landing site. This has been done in figures 6 to 8 for a range of landing-site latitudes and longitudes.

Illustrated in figure 6 is a case where the curve of figure 4 marked "bad" is used as a boundary between acceptable and unacceptable lighting. In this case, a landing site at zero longitude, zero latitude would have acceptable lighting during the full 14.75 days of earthshine, while a site at longitude 0° latitude 50° would not have acceptable lighting until the second day after terminator passage; the lighting would remain acceptable until the 13th day.

Similar interpretations can be made using the lines marked "marginal" and "good." The data for such interpretations are presented in figures 7 and 8, respectively. Based on figures 6 to 8, envelopes are plotted in figures 9 to 11 to show the range of earth days having suitable lighting for lunar operations after sunset, where the boundary values are taken as bad, marginal, and good lighting conditions, respectively.

It is readily apparent, from an inspection of figures 9 to 11, that landing sites near the center of the lunar disk afford the greatest number of days with suitable lighting for lunar operations and that as a prospective landing-site position is moved away from the disk center, the total number of days with suitable lighting rapidly decreases. In addition, it is apparent that surface exploration can extend throughout the entire lunar night only if bad lighting conditions are tolerated during the first and last portion of the lunar night and only if such exploration regions are near the lunar-disk center.

Although the number of days of good lighting which would prevail at a given landing-site position could be determined from figures 9 to 11, the limited subjective nature of the earthshine investigation precludes such quantified results. Before the numerical results of this investigation can be applied to Apollo mission planning, a more thorough investigation must be conducted in which such factors as earth-albedo variation, earthshine color, reflective properties of test-bed, visual acuity of test subjects, criteria for acceptable visibility conditions, and lunar librations are considered.

CONCLUSIONS

A limited subjective investigation of the adequacy of earthshine for lunar-surface operations was conducted utilizing neutral-density filters to simulate earthshine and utilizing the MSC lunar-surface simulation as a test ground. The lighting conditions were considered to be good if the test subjects indicated, subjectively, a sense of confidence in their ability to traverse the rougher portions of the simulation and if they were able to distinguish the relief of distant features such as craters. It was assumed that an auxiliary light would be available to illuminate shadowed areas.

Although the earthshine evaluation was quite subjective and limited in the amount of test data collected, the results indicated that under certain conditions earthshine is adequate for lunar operations. The results further indicated that as the landing-site arc distance from the mean libration point increases, the number of days of suitable lighting rapidly decreases. Only landing sites near the center of the lunar disk appear to afford suitable lighting conditions throughout the lunar night.

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National Aeronautics and Space Administration
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914-50-10-06-72

REFERENCES

1. Kuiper, G. P.: The Earth as a Planet. Univ. of Chicago Press (Chicago, Ill.), 1954, ch. 15.

2. Anon.: Explanatory Supplement to the Ephemeris. Her Majesty's Stationery Office (London), 1961, ch. 13.

TABLE I. - RESULTS OF EARTHSHINE EVALUATION TESTS

Filter	Test no. 1, simulated landing site arc distance, 20°			Test no. 2, simulated landing site arc distance, 52°		
	Simulated earthshine intensity, 10^{-3} lm/cm^2	Subject no. 1	Subject no. 2	Simulated earthshine intensity, 10^{-3} lm/cm^2	Subject no. 1	Subject no. 2
1	0.22	Bad	Bad	0.12	Bad	Bad
2	.44	Marginal	Marginal	.25	Bad	Bad
3	.91	Good	Good	.47	Bad	Bad
4	2.91	Good	Good	1.50	Marginal	Marginal
5	3.88	Good	Good	2.26	Good	Good

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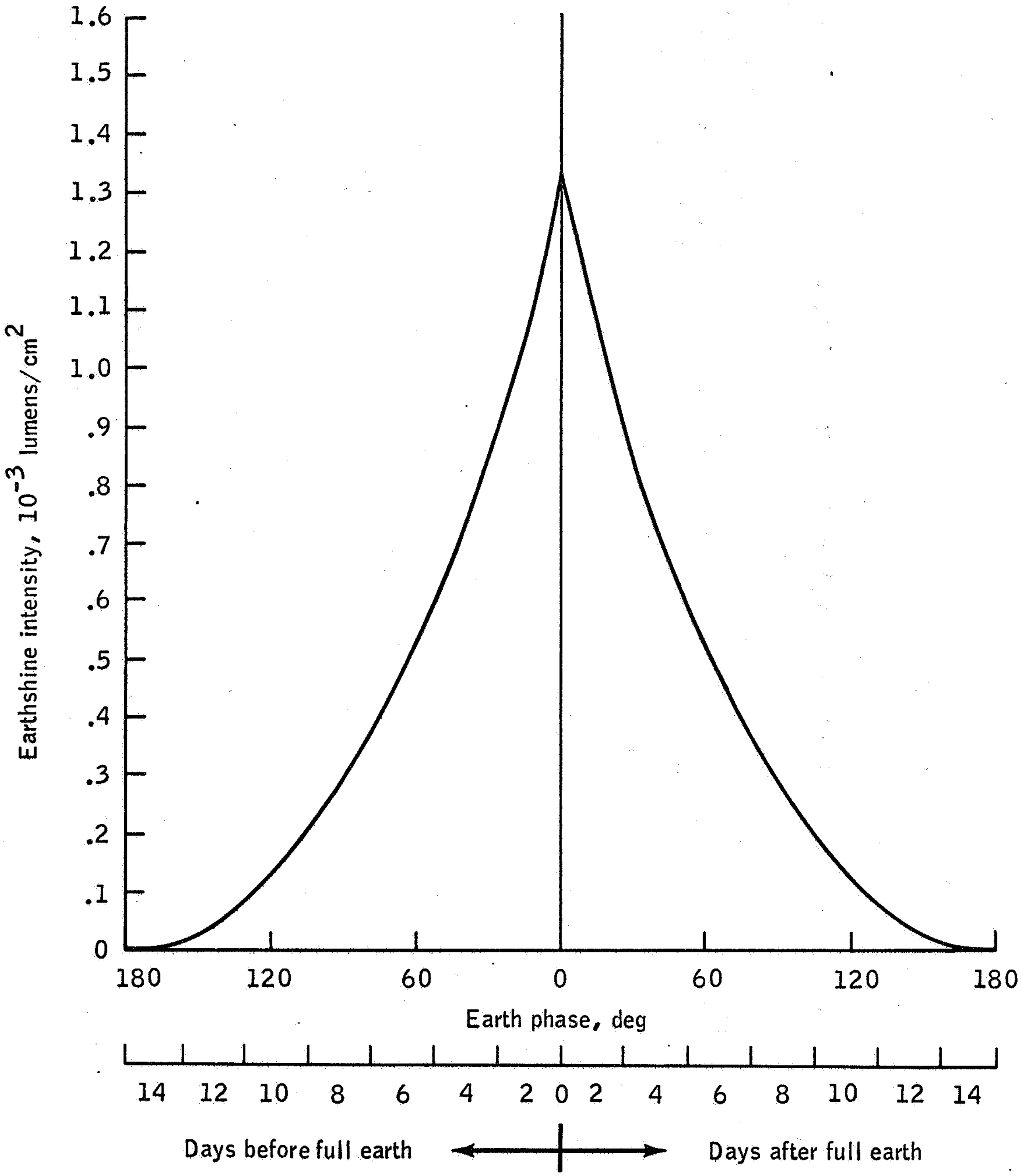

Figure 1. - Earthshine intensity on the moon as a function of earth phase.

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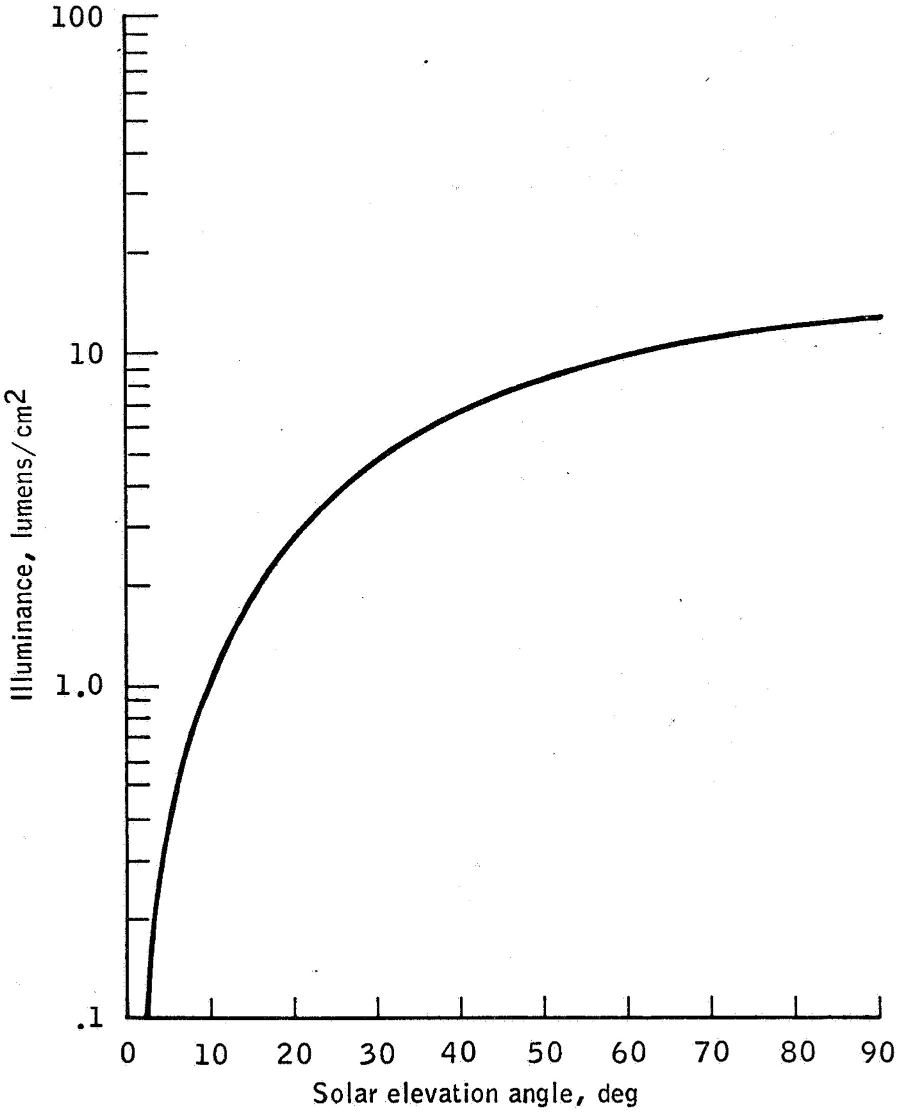

Figure 2. - Total solar illuminance on the earth as a function of solar elevation angle.

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Figure 3. - Photograph of one of the rougher areas of the MSC lunar simulation.

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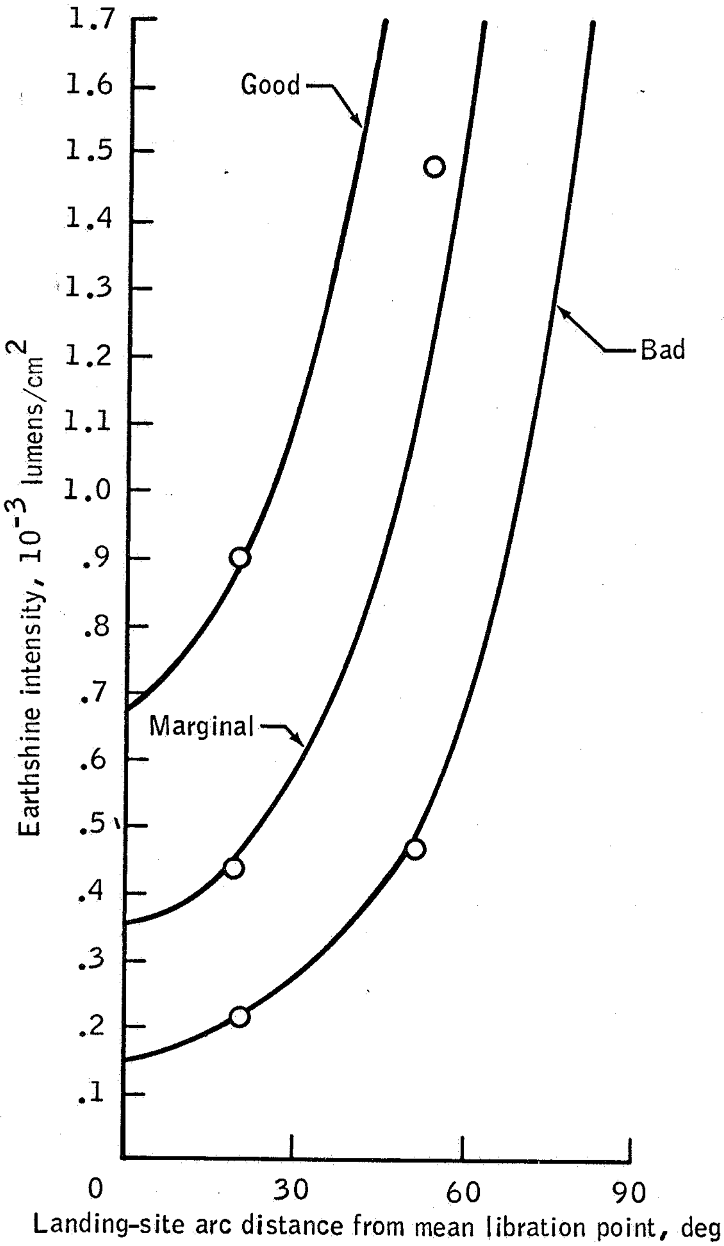

Figure 4. - Results of earthshine investigation plotted and extrapolated to show acceptability of earthshine for lunar operations as a function of landing-site position.

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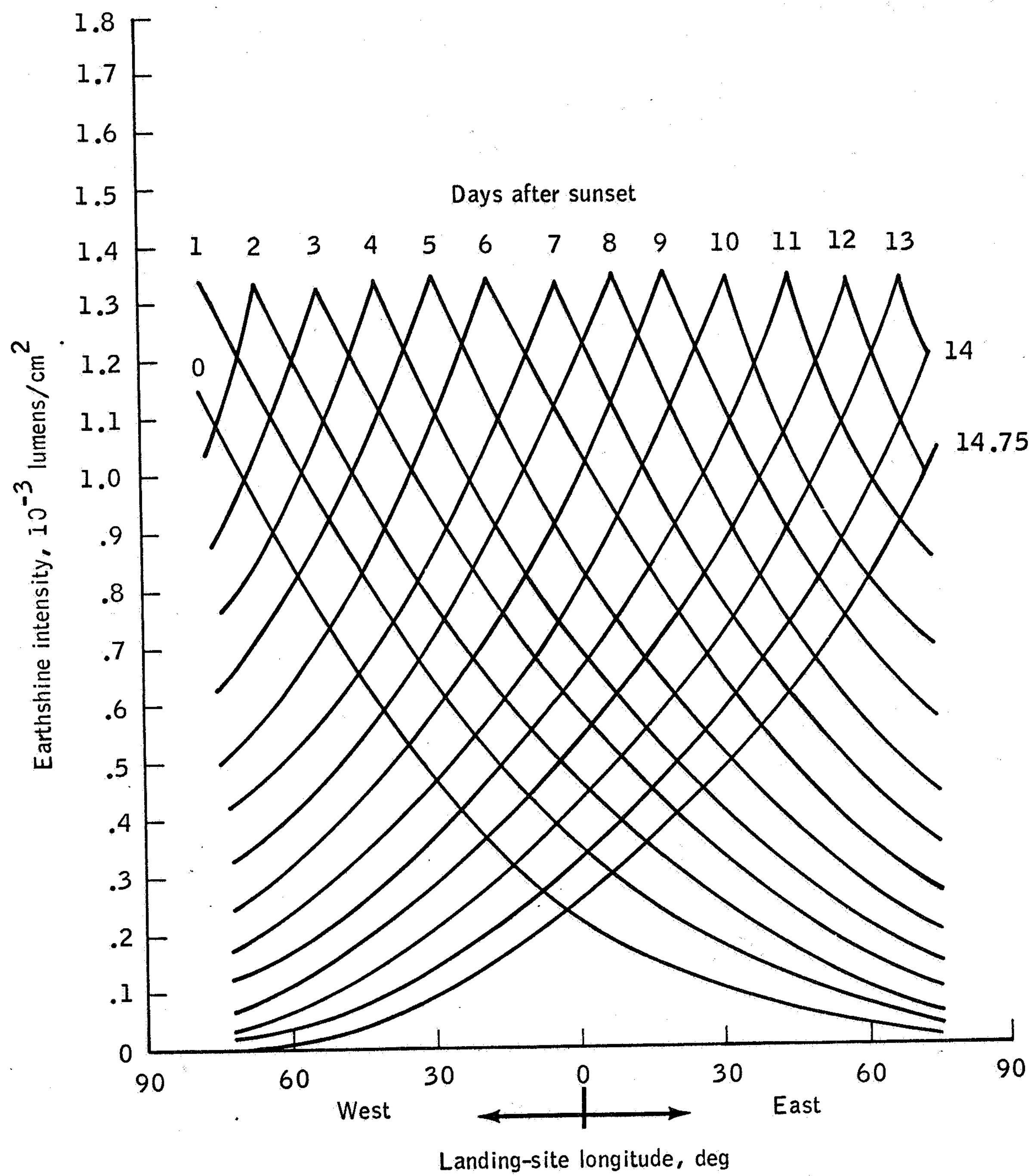

Figure 5. - Earthshine intensity for a given landing-site longitude as a function of days after sunset.

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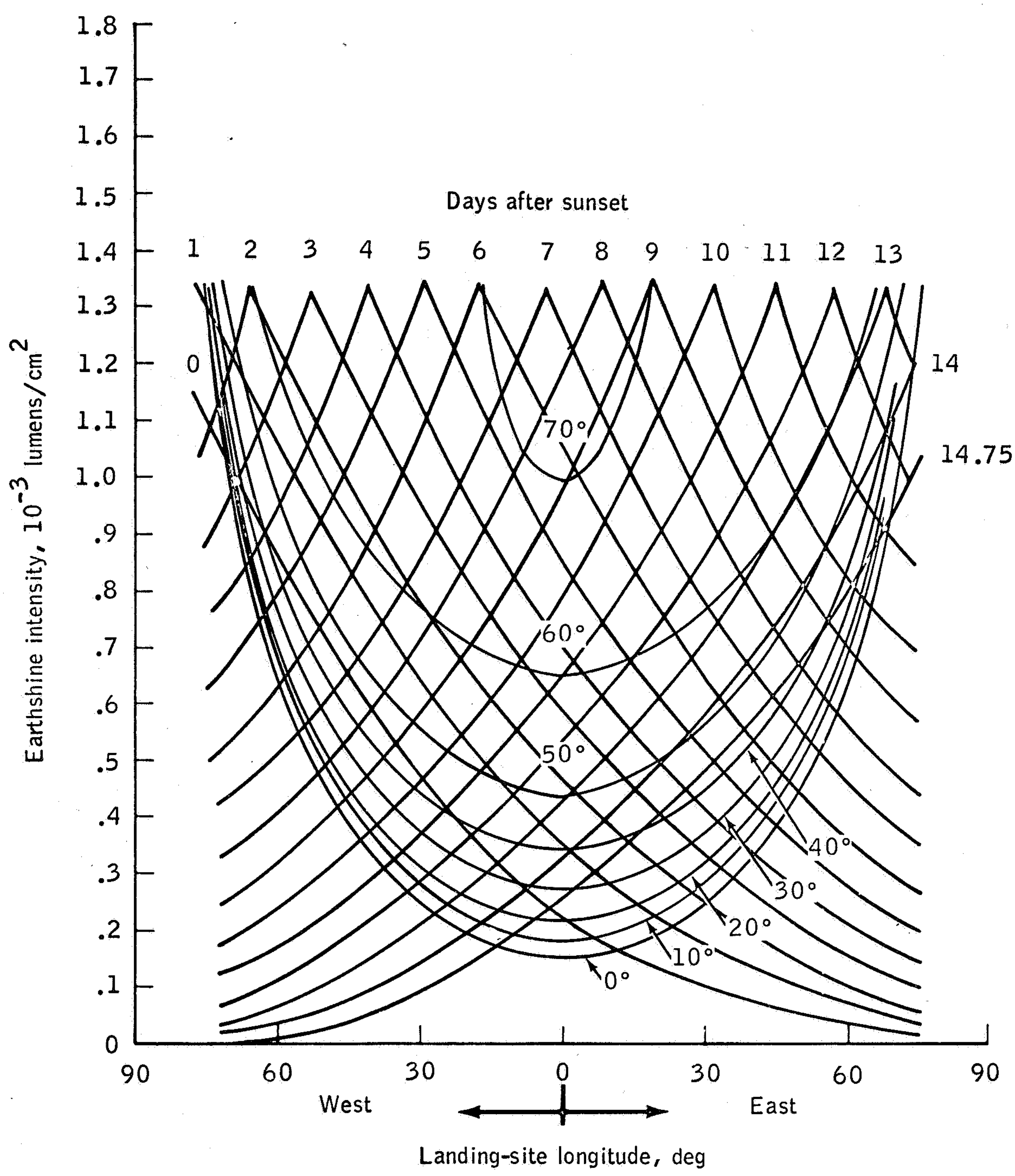

Figure 6. - Period of time during lunar night when suitable lighting conditions exist for lunar operations as a function of landing-site longitude and latitude where the line marked "bad" in figure 4 is used as the boundary.

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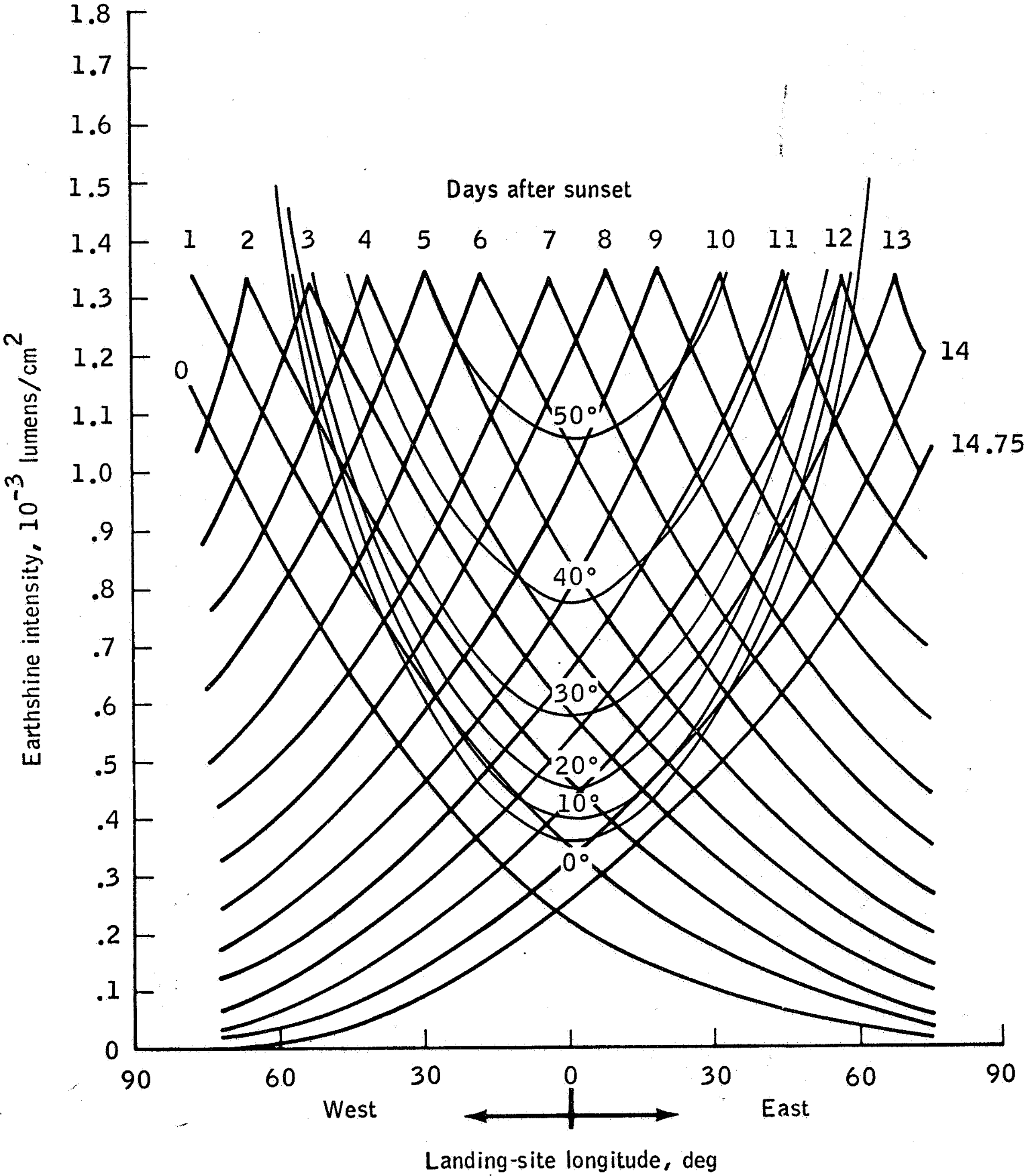

Figure 7. - Period of time during lunar night when suitable lighting conditions exist for lunar operations as a function of landing-site longitude and latitude where the line marked "marginal" in figure 4 is used as the boundary.

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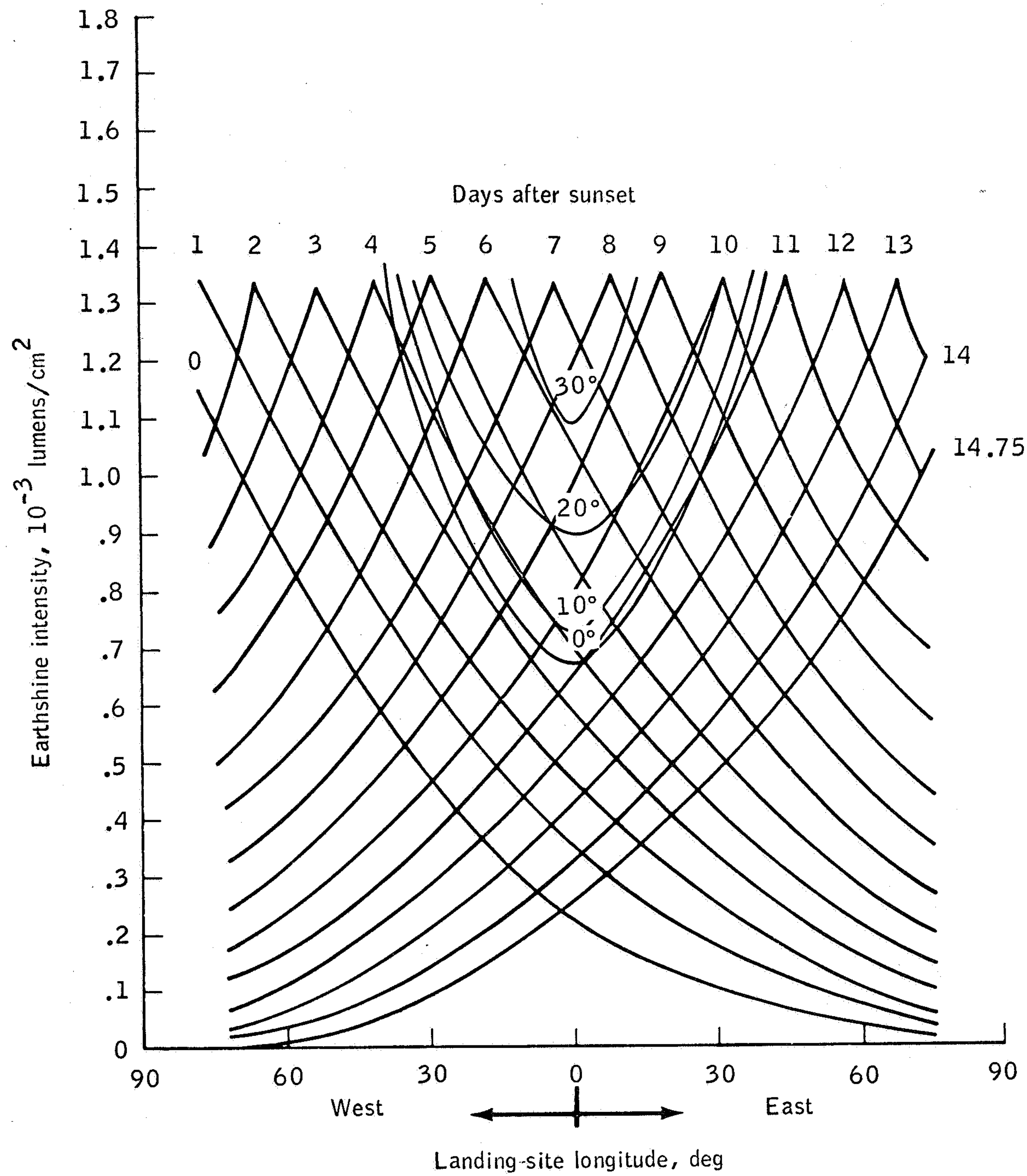

Figure 8. - Period of time during lunar night when suitable lighting conditions exist for lunar operations as a function of landing-site longitude and latitude where the line marked "good" in figure 4 is taken as the boundary.

NASA-S-67-5658

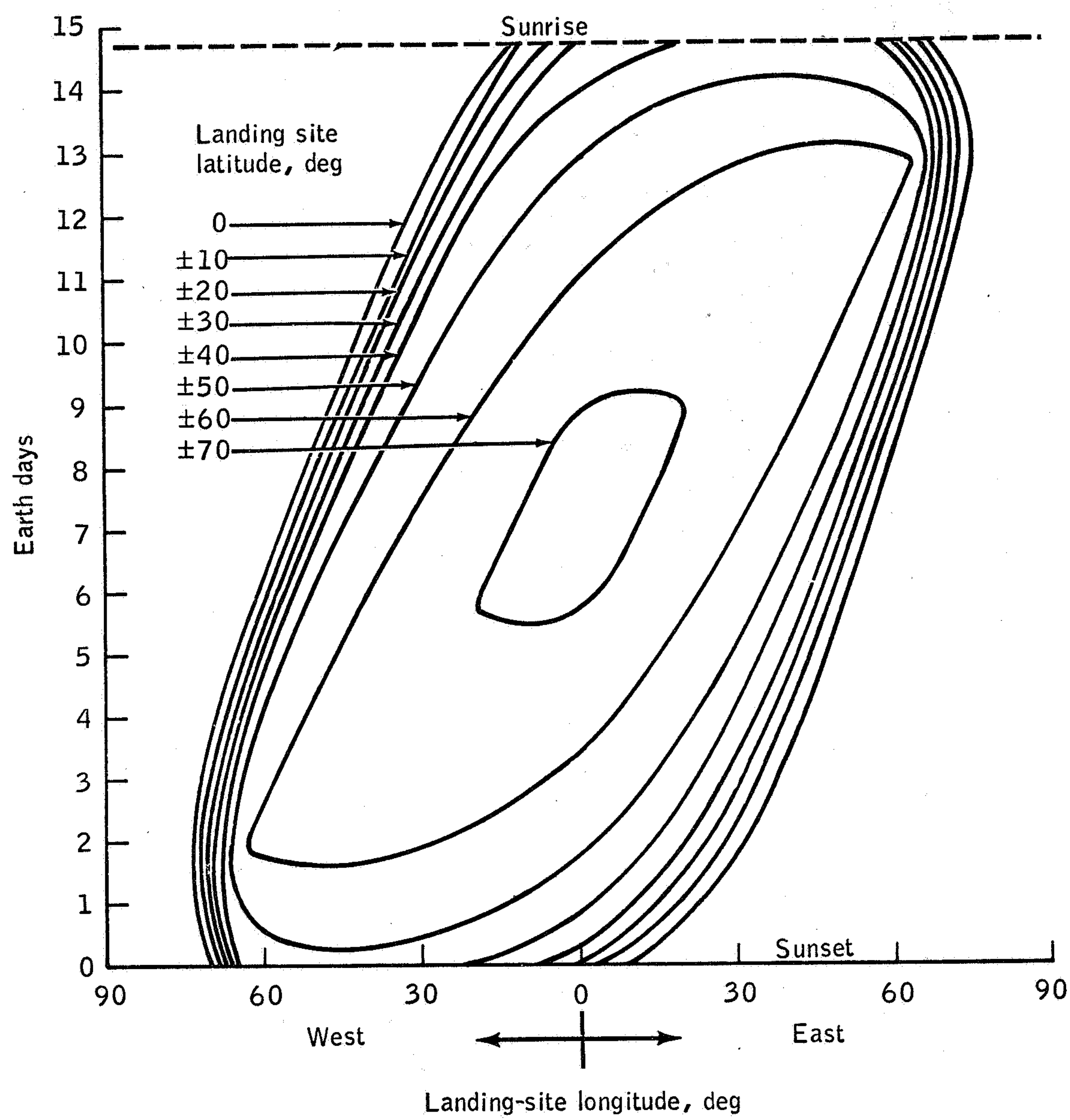

Figure 9. - Envelope showing the period of days during the lunar night with suitable lighting for lunar-surface operations where the line marked "bad" in figure 4 is taken as the boundary.

NASA-S-67-5656

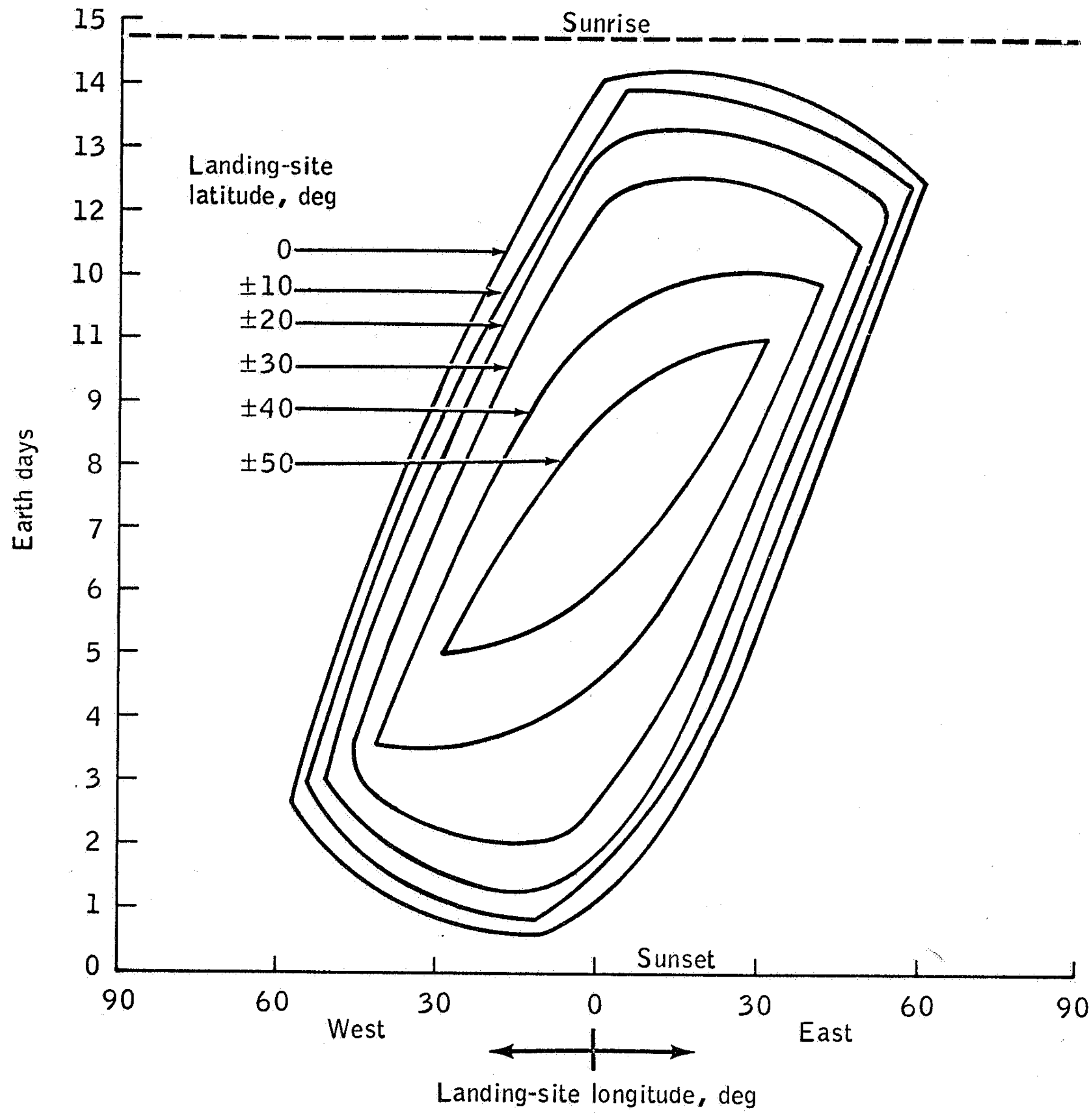

Figure 10. - Envelope showing the period of days during the lunar night with suitable lighting for lunar-surface operations where the line marked "marginal" in figure 4 is taken as the boundary.

NASA-S-67-5657

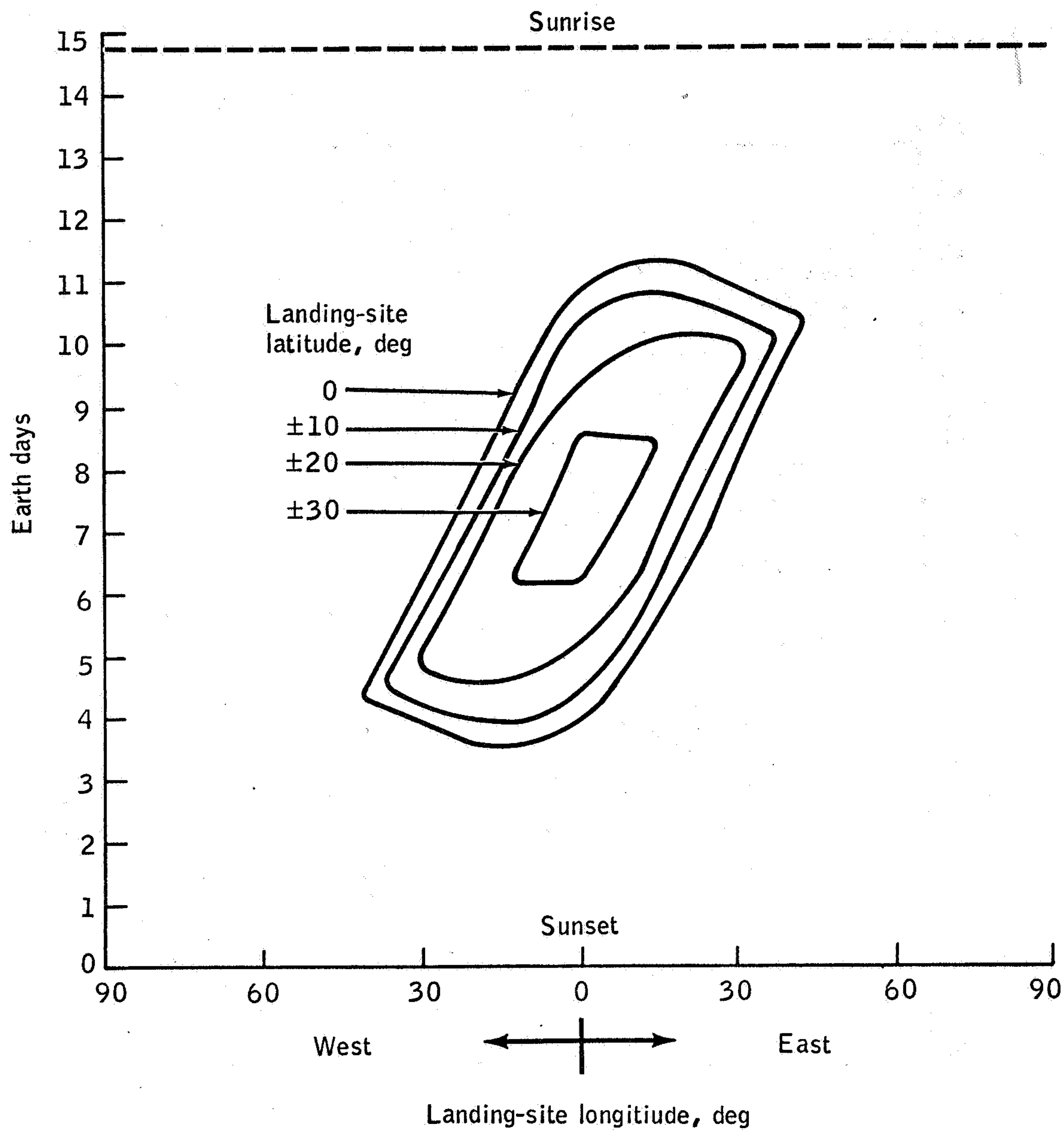

Figure 11. - Envelope showing the period of days during the lunar night with suitable lighting for lunar-surface operations where the line marked "good" in figure 4 is taken as the boundary.